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The Use of Bonded Rubber Pads for the
Application of Loads for Structural
Testing of the P-3 Orion Leading Edge

G. Luke and T.J. van Blaricum

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G. Luke and T.J van Blaricum

**Airframes and Engines Division
Aeronautical and Maritime Research Laboratory**

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ABSTRACT

Aerodynamic loads on aircraft lifting surfaces are often due to negative pressures acting on the outer skin of the structure. To simulate this type of loading, rubber pads bonded to the skin and loaded in tension can be used. This report describes the development of a contact adhesive based bonded rubber tension pad system for testing of an Orion P-3 wing leading edge.

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Executive Summary

Aerodynamic loads on aircraft lifting surfaces are often due to negative pressures acting on the outer skin of the structure. To simulate this type of loading, rubber pads bonded to the skin and loaded in tension can be used. This report describes the development of a bonded rubber pad for testing of an Orion P-3 wing leading edge section.

The design goal for the tension pads was to develop a system which could operate reliably for an extended period of time under static loading conditions at an average working stress up to 0.5 MPa based on the area of the tension pads. This working stress would support Design Ultimate Load (DUL) with adequate margin of safety.

The design goals were demonstrated by testing tension pads of equivalent size under static loading conditions to ensure satisfactory results were obtained. A limited number of pads were also tested under constant amplitude loading conditions to assess their suitability for fatigue testing..

The pad design incorporated metal backing plates which were used to transform the point load from the whiffle tree across the plate to a distributed load at the surface of the leading edge. To obtain even load transfer into the leading edge structure, relatively thick backing plates (9.5 mm) were used to minimise deflection. The detail design of the backing plate to whiffle tree attachment point was tailored to achieve an even load distribution across the surface of the plate.

The rubber tension pads comprised a Linatex 25 mm natural rubber sheet attached to the backing plates using a two part epoxy adhesive marketed by Linatex Australia as Solufix 14, Part A being the base adhesive and Part B the hardener. The same adhesive was also used to bond the tension patches to the test article. Prior to bonding the surface of the backing plates and the test article were cleaned and prepared for bonding and pre-treated with Linatex MP21 primer to promote adhesion. To increase bond strength to acceptable levels the test article was subjected to an adhesive post cure cycle at 45 degrees Celsius. The bonding and post cure process used here was developed to give consistent satisfactory results for the leading edge test program however the process was not optimised for maximum bond strength.

The tension pad loading system performed satisfactorily for the duration of the Orion leading edge investigation and was able to sustain loads of up to DUL without disbonding.

Authors

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1. Introduction

Aerodynamic loads on aircraft lifting surfaces are often due to negative pressures acting on the outer skin of the structure. To simulate this type of loading, rubber pads bonded to the skin and loaded in tension are often used. In this report the development of a bonded rubber pad for testing of an Orion P-3 wing leading edge section is described. The design of the pads was application driven, so the range of parameters studied was limited to finding a satisfactory result rather than an optimum design. The A number of tension pads were manufactured to the final design and then tested to develop confidence in the procedures used.

2. Tension Pad Requirements

The design goals for the tension pads are shown in Table 1. The average stress level was the stress obtained by dividing the applied load on the pad by the nominal pad area. At the limit stress level, a tension pad was considered satisfactory if there was no visible rupture (peel/break) at the edge of the adhesive interface. The ultimate stress level was 1.8 times the limit stress and at this stress the tension pad may have a visible rupture but must remain capable of sustaining the load for a reasonably long period of time. The design goals were demonstrated by tension pads of equivalent size intended for loading of the Orion leading edge assembly and with similar load reaction constraints.

3. Tension Pad Design

A tension pad consists of a loading tab welded normal to a rigid steel backing plate which is bonded to a flexible rubber pad. The rubber pad is then bonded onto the surface to be loaded using a contact adhesive. In the following sections the design of the steel backing plate is discussed and the bonding process is described.

3.1 Backing Plate Design

The metal backing plate converts the point load from the whiffle tree across the plate to a distributed load at the surface. The Orion wing leading edge loads were applied using backing plates of two basic sizes, referred to here as small and large backing plates. The purpose of each backing plate was to transfer load to the rubber in an evenly distributed manner. This was done by using a relatively thick (9.5 mm) mild steel plate to minimise the deflection of the base plate under load. In addition, the loading tab attached to the backing plate was welded in short lengths away from the centre of the plate to act as primary load paths. Additional gussets were welded to the

large backing plates main loading tab to further distribute the load over the backing plate. The final backing plate designs used for the tension pads to load the Orion wing leading edge are shown in figure 1.

3.2 Bonding Process

The rubber tension pads were attached to the backing plates and the test item using a two part epoxy adhesive marketed by Linatex Australia as Solufix 14, Part A being the base adhesive and Part B the hardener. The pink coloured rubber sheet (25 mm thick) is a Linatex product specified simply as "95% pure natural rubber manufactured from fresh field latex" Prior to bonding to any metal surface Linatex MP21 primer was used to promote adhesion. The final bonding process developed for the Orion wing leading edge static test is described in Appendix 1. The bonding process described in Appendix 1 is not to be taken as the optimum procedure for bond strength, however, it was a procedure which gave consistent satisfactory results during the tension pad development program .

4. Description of Tests

There were several tests conducted to determine a suitable tension pad design to apply the loading required for the Orion wing leading edge. The tests can be divided into several distinct groups which are briefly described in the following paragraphs. All tests were conducted in an axial test machine operating under load control.

4.1 Initial Concept Testing (Group A)

This group of tests was conducted for a limit stress requirement of 0.2 MPa which was the original stress level envisaged for the Orion leading edge test. The backing plates used in these tests were simple square aluminium plates with a fitting screwed into a threaded hole in the plate centre to apply load from the test machine. The size of the test specimens varied from 50 mm to 100 mm square. The adhesive was cured at room temperature and the hole in the centre of the backing plate was drilled and tapped after bonding was completed, and may have damaged the adhesive layer. A typical test piece is shown in Figure 2.

4.2 Representative Tension Pads (Group B)

Following the successful demonstration of the bonding method, the next stage was to test larger tension pads with a backing plate representative of the type and size to be used to load the Orion wing leading edge. For these tests, two steel backing plates and a steel base plate were made according to the design shown in Figure 3. The rubber

was bonded to the backing plates with the adhesive cured at room temperature , as with the tests in Group A. The base plate was designed to be suitable for use with either backing plate.

Results of Group B tests using the new design were promising but still failed below the desired ultimate stress level, particularly for the larger tension pads. The better performance of the smaller tension pad prompted changing the single large pad to a pair of smaller pads on a single large base plate, as shown in Figure 4. The corners of each pad were rounded to reduce stress concentration effects. Only a single test was made with this double tension pad design which gave definite improvement. It was decided that using a double pad for larger areas was better than the single pad, so the double pad design was retained.

4.3 Adhesive Cured at Elevated Temperature (Group C)

The poor results obtained in Group B tests prompted discussion with Linatex chemists, from which it was decided that curing the adhesive at an elevated temperature may improve bond strength and decrease the curing time. A consideration for the curing temperature was the effect of heat on any strain gauges installed on the wing leading edge structure during bonding of the tension pads. Consequently, a cure temperature of 45 degrees Celsius was selected.

Following initial tests in Group C the cure temperature was increased to 60 degrees Celsius to bond the rubber to the steel backing plates. In addition to curing the adhesive at an elevated temperature all specimens in Group C had an aluminium sheet attached to the steel base to simulate the Orion wing leading edge surface.

A significant improvement in bond strength for all pad sizes was observed, except in one instance with a smaller tension pad when a poor bond resulted from application of excessive clamping at the edge of the pad, resulting in the centre area losing contact with the aluminium surface during curing. The failure in this instance, at 0.5 MPa, was still above the required ultimate average stress of 0.45 MPa

4.4 Simulating Orion Leading Edge Rib Position (Group D)

After satisfactory results were obtained with tension pads in Group C, further tests simulating the tension pads bonded over a rib of the leading edge were conducted. The aim of these tests was to look at the effect of a change in the stiffness characteristics of the loaded surface. In Figure 5 the typical deflection of the aluminium sheet and rubber is shown for tests in groups C and D. Note that due to the localised deflections of the aluminium sheet the actual stress at the point of failure for tension pads in Groups C and D could be significantly higher than the nominal stress level reported here.

4.5 Fatigue Tests (Group E)

A limited number of fatigue tests of the bonded tension pads were conducted to explore the endurance qualities of the adhesive. Although the tension pads were intended to apply only static loads for the wing leading edge tests, there was the strong possibility that a number of smaller static loadings of the structure would need to be applied prior to testing to ultimate load conditions. For this reason a single fatigue test at a maximum average stress of 0.2 MPa (the original limit stress specified for the leading edge test) was conducted on a specimen from Group A. A later requirement for use of bonded rubber pads to apply loads to the empennage assembly for full scale fatigue testing of the PC-9 trainer aircraft prompted a limited investigation into the fatigue performance of the heat cured adhesive.

Three fatigue test specimens were prepared with 50 mm by 75 mm rubber pads, representative of the size to be used in the PC-9 full scale fatigue test. The expected applied peak load gave an equivalent nominal stress of approximately half the average design limit stress for the pads. Two of the tests used constant amplitude loading with a maximum stress of 0.13 MPa and minimum stress of 0.013 MPa and -0.13 MPa respectively. The third test used a flight type load sequence with a maximum stress of 0.13 MPa. At the conclusion of the nominated number of fatigue cycles, the test items were failed under static load conditions to establish the residual strength.

5. Test Results

5.1 Static Tests

Table 2 gives the results for each group of static tests completed. Comparison of the average stress at failure is shown. These results include the "learning curve" on bonding the rubber to the metal surfaces, hence, the best strength is obtained from experienced bonding personnel. A batch of tension pads were made for the Orion leading edge static test. A single pad, measuring 60 mm by 150 mm, was selected at random and tested. This was done to confirm that the results of the development tests were applicable to the finished tension pads. The result of this test is included with the comparable data of Group C development tests.

The results are shown graphically in Figure 6 for groups A and B. Figure 6 shows a decrease in bond strength with respect to the increase in load area and that the performance of the large pads did not meet the ultimate stress requirement. Figure 7 shows the relative failure stress of the hot cured pads from groups C and D which are representative of the tension pad areas to be used on the leading edge static test. Also shown in Figure 7 is the results from Group A for comparison.

5.2 Fatigue Tests

The results of the fatigue test items are shown in Table 3. The constant amplitude loading was considered more severe than the PC-9 flight sequence used in the final fatigue test as the peak load in the flight sequence was of equal magnitude to the maximum load in the constant amplitude loading. The number of cycles completed prior to the residual strength test was based on the full scale PC-9 test running for 200 flight programs. Test frequency for the 50 mm by 75 mm specimen was 10 Hz.

6. Discussion of Results.

Table 4 lists the maximum tensile load and nominal stress applied by the four different sizes of tension pad used to test the Orion wing leading edge section. Also shown for each size of tension pad is the range of test results from Groups C and D along with the reserve factor based on the minimum demonstrated capacity of the tension pad. These results indicated that with the heat cured adhesive, the reserve factor (RF) for each pad size to be used to load the Orion wing leading edge was greater than 1.8 times the intended applied stress. The maximum load applied to each pad is also shown.

In Figure 8 the nominal failure stress range is shown for each size of tension pad. For the smaller pads the failure range was quite high, with an obvious trend for the failure stress range to decrease as the pad area increased. This suggests that for the larger tension pads local stress concentrations are more important than the nominal stress value used here for the purposes of comparison. Generally, the results improved as the AMRL staff responsible for the bonding gained experience and improved the process.

The fatigue test results of group E indicate that the adhesive process used was not fatigue sensitive at the maximum average stress applied, which was just over half the 0.25 MPa limit stress requirement. The residual strength of these specimens after completion of the fatigue cycles was far greater than the strength achieved by earlier tests using a cold cured adhesive and fatigue resistance was improved by curing the adhesive at an elevated temperature.

7. Conclusions

A simple bonded rubber tension pad system was developed to apply negative pressure loads on the Orion wing leading edge for a static structural test. The bonding process used is described in Appendix 1 of this report. The features of the tension pads are:

- A rigid backing plate to promote an evenly distributed load over the rubber pad area.
- Rounded corners on the rubber pad to reduce stress concentrations.
- A hot cured contact adhesive to achieve high bond strength and fast curing.
- Multiple rubber pads for larger load areas (above 15 000 mm²)

The tension pad design described here was developed specifically for the Orion wing leading edge task and should not be considered as an optimum design for general applications. Further investigation of cure temperatures and time, rubber pad thickness and fatigue performance may lead to significant improvements. The use of the Linetex bonded rubber tension pads was demonstrated as a suitable means of simulating aerodynamic pressure loads for structural test purposes provided the loads do not exceed the margins demonstrated.

8. Acknowledgements

Initial tests of bonded rubber pads described in Group A were conducted by Mr D. Aker and Mr M. Richmond. The successful application of a bonded rubber tension patch loading system for the Orion leading edges test would not have been possible without the considerable effort of AED technical officers Mr R. Bailey and Mr R. Dingley who developed the surface preparation and bonding procedures.

Table 1. Tension Pad Design Goals.

Property	Design Goal
Design Limit Average Stress Level	0.25 MPa
Design Ultimate Average Stress Level	0.45 MPa

Table 2 - Test Results By Group

Group	Pad Size (mm by mm)	Load (Newtons)	Stress (MPa)
A	50 x 50	1500	0.600
	50 x 50	1650	0.660
	75 x 75	3000	0.530
	100 x 100	4500	0.450
B	60 x 200	6000	0.500
	60 x 200	6500	0.540
	150 x 200	7450	0.250
	150 x 200	9900	0.330
	2 x 75 x 200	9350	0.310
C	60 x 150	8250	0.911
	60 x 200	6000	0.500
	60 x 200	10500	0.875
	60 x 200	12000	1.000
	60 x 200	13250	1.104
	2 x 75 x 150	10000	0.444
	2 x 75 x 150	17500	0.778
	150 x 200	13000	0.433
D	60 x 200	7500	0.625
	60 x 200	10550	0.871
	2 x 75 x 200	18250	0.608

Table 3 - Fatigue Test Results.

Pad Size (mm by mm)	Load Range (Newton)	Type	Cycles completed	Static Load (Newtons)	Stress (MPa)
100 x 100	100 to 2000	CA	30 250	n/a	0.200
50 x 75	50 to 500	CA	2 000 000	2000 ¹	0.530
50 x 75	-500 to 500	CA	3 000 000	5750	1.530
50 x 75	-210 to 500	Flight	400 Programs	7750	2.060

Note 1: Did not fail at this load.

Table 4 - Applied Test Loads for P3 Leading Edge Centre Section

Pad Area (mm ²)	Width x Depth (mm)	Max Load (N)	Nominal Stress (MPa)	Test Range (MPa)	RF
9000	150 x 60	1450	0.16	0.91	5.7
12000	200 x 60	2150	0.18	0.50 - 1.104	2.8
22500	150 x 150	4050	0.18	0.44 - 0.778	2.4
30000	200 x 150	5700	0.19	0.43 - 0.608	2.3

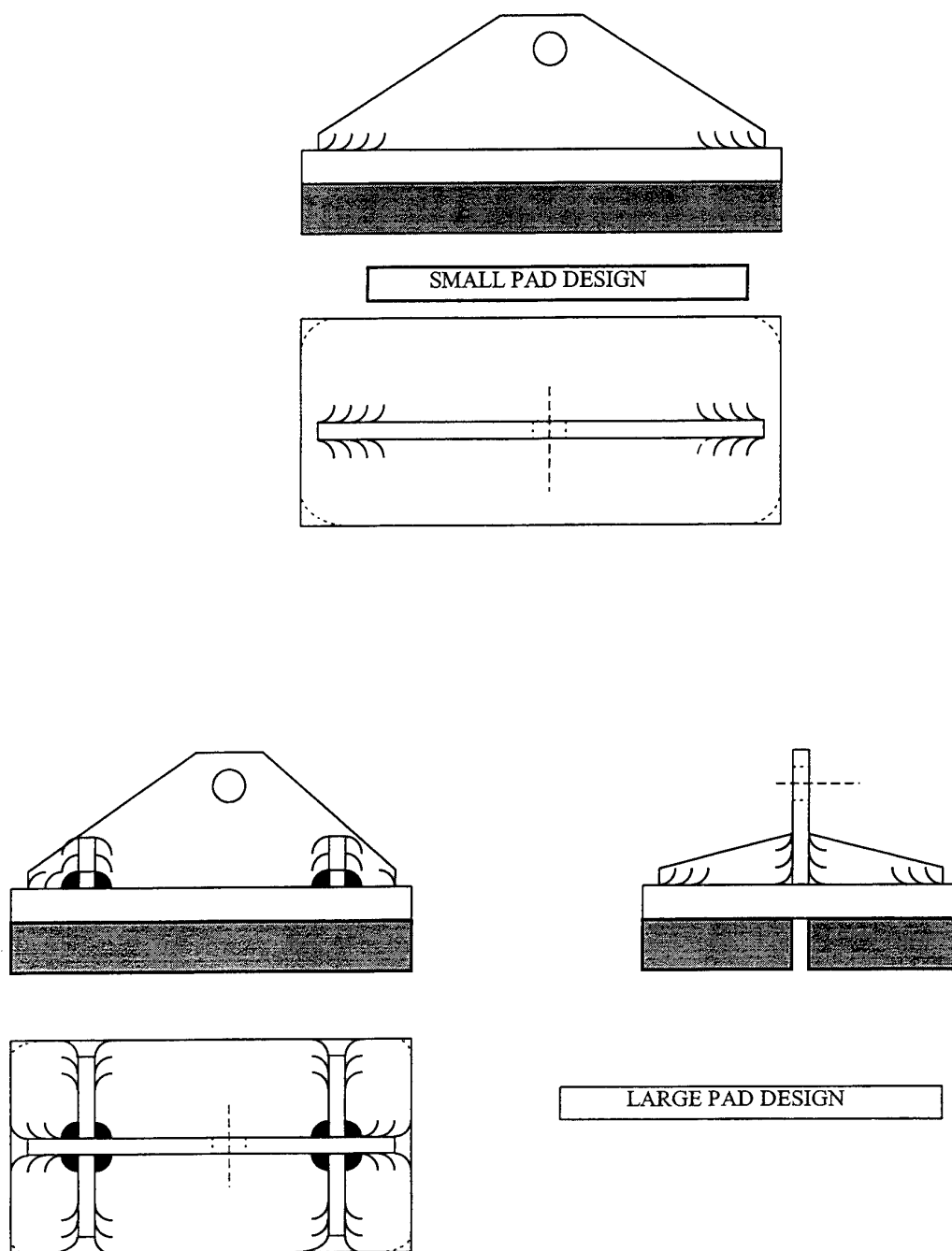


Figure 1: Final Pad Design

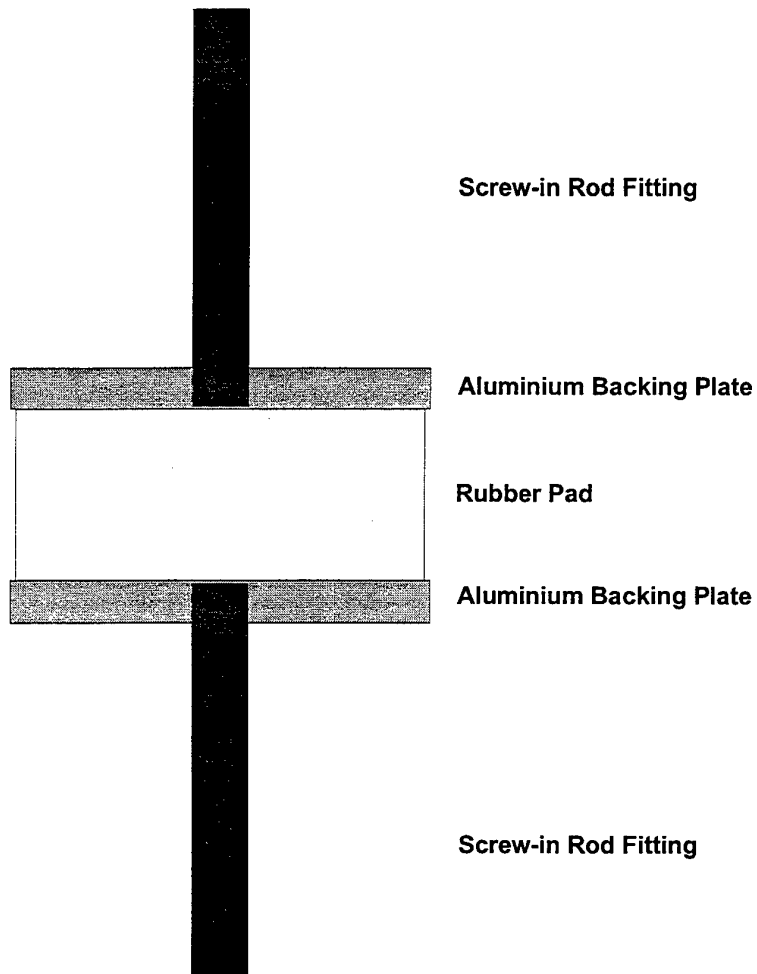
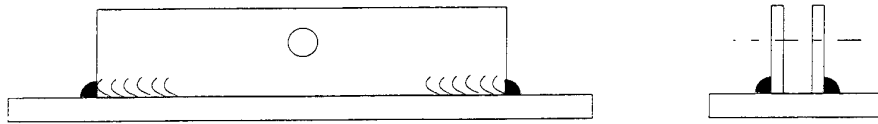
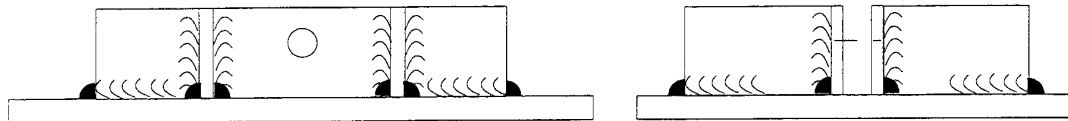


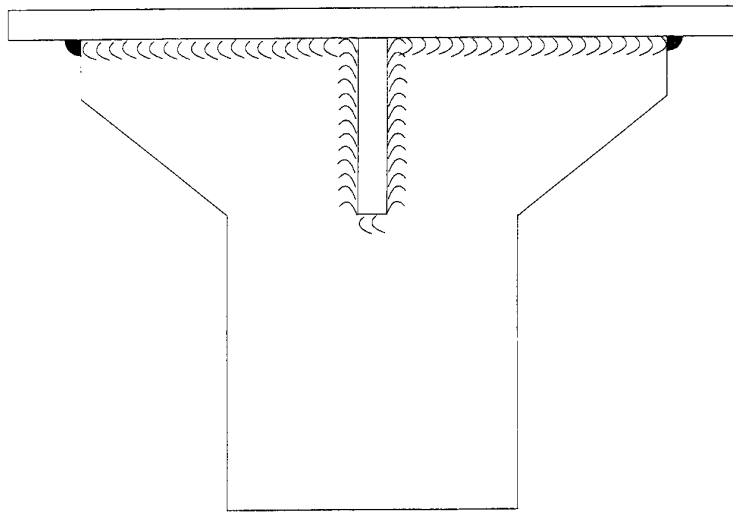
Figure 2: Test Specimen for Group A.



Small Backing Plate.



Large Backing Plate.



Base Plate

Figure 3: Backing Plate and Base Plate for Groups B, C and D.

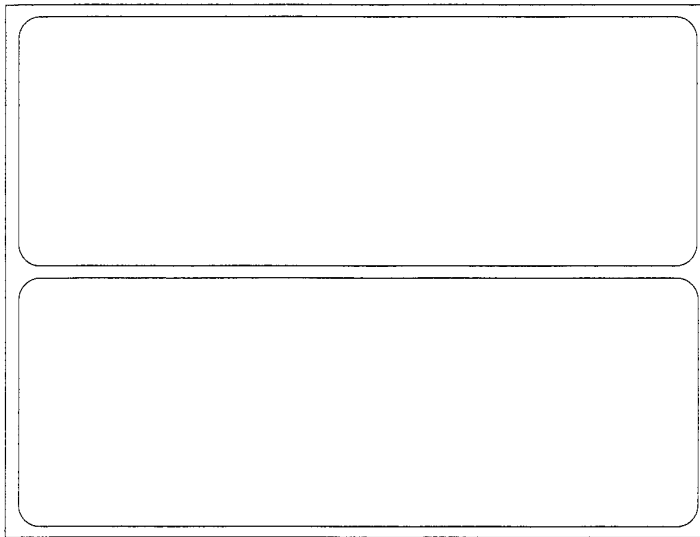


Figure 4: Dual Pad Design For Large Tension Pads.

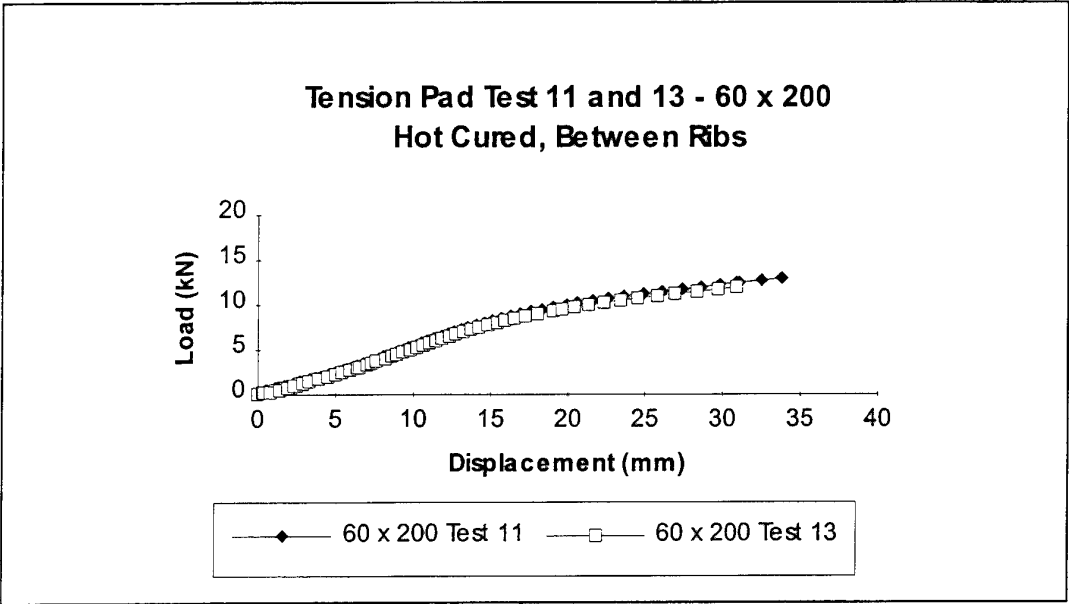


Figure 5a : Typical Deflection of Aluminium/Rubber , Group C

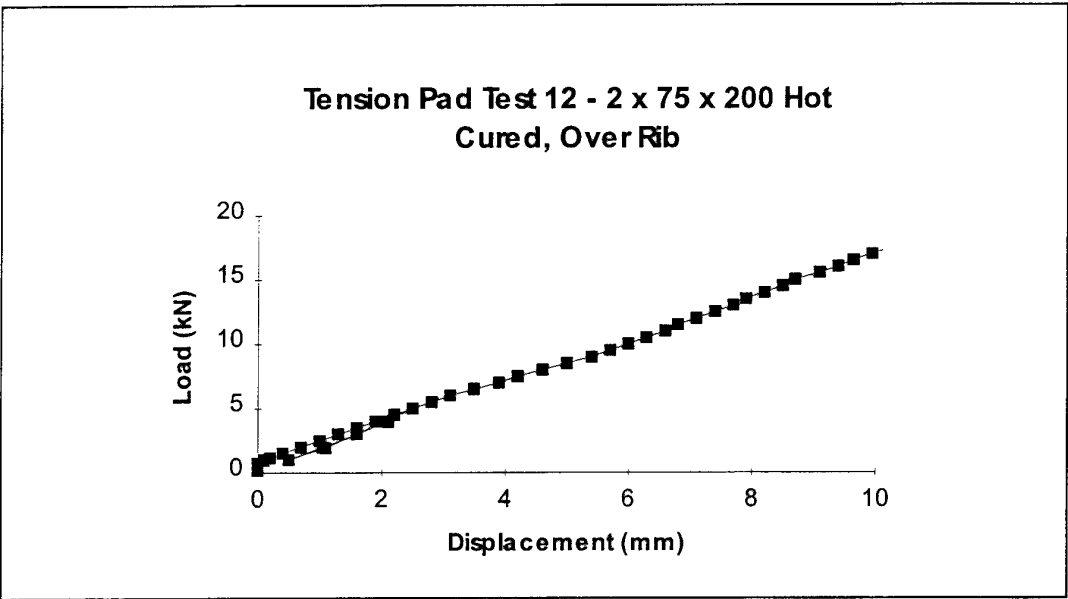


Figure 5b : Typical Deflection of Aluminium/Rubber , Group D

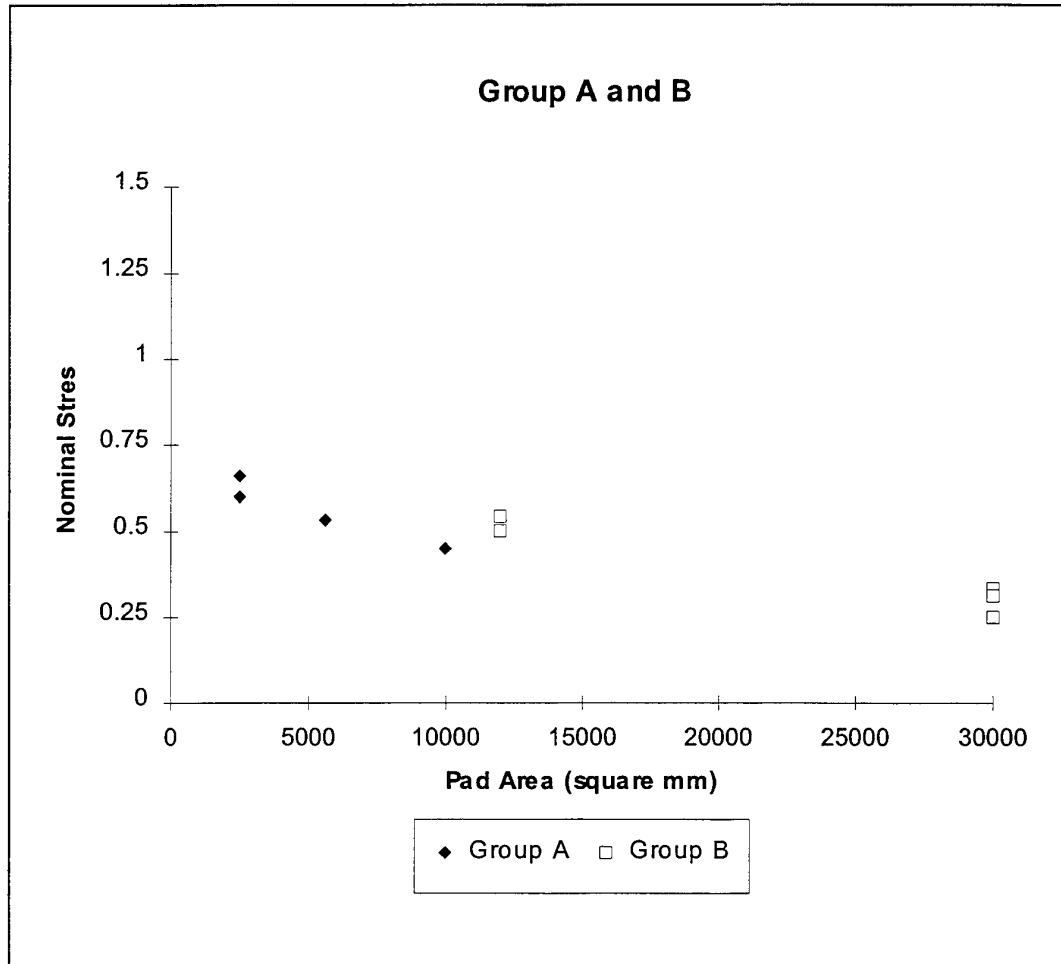


Figure 6: Test results from Group A and Group B

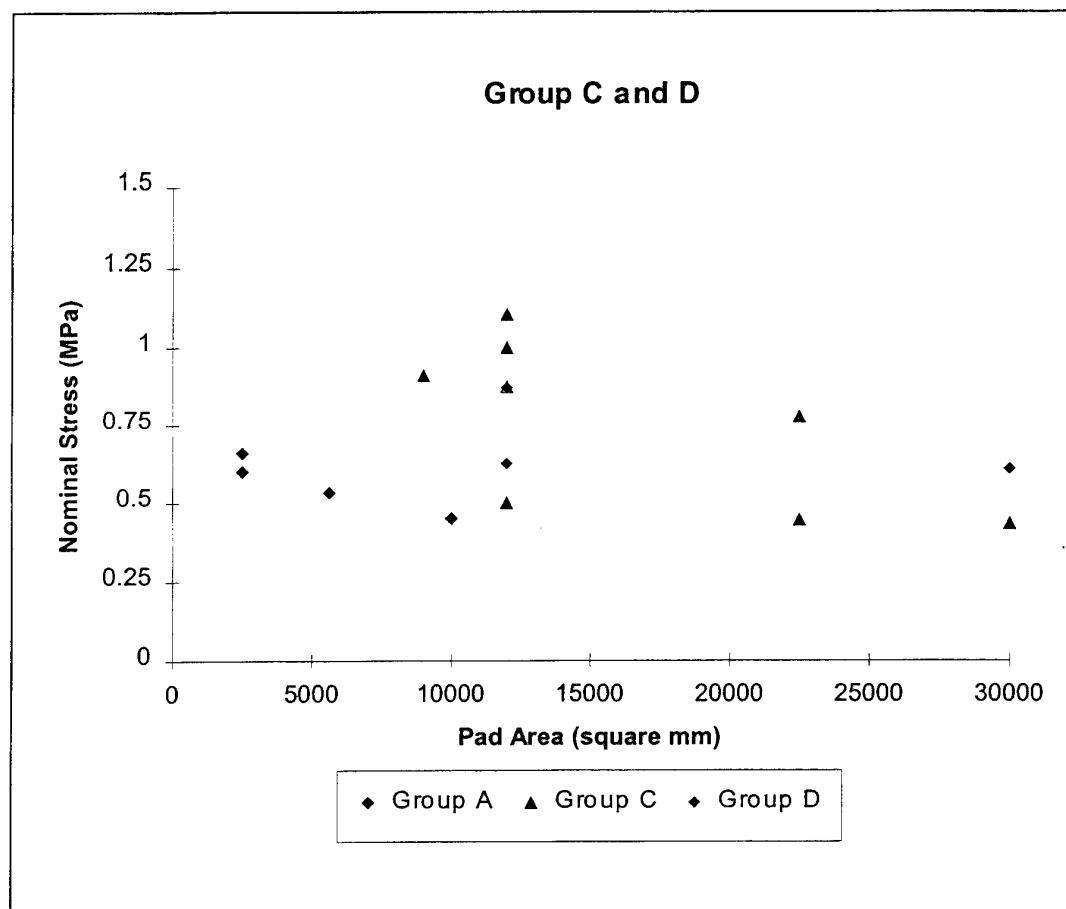


Figure 7: Test results from Group C and Group D

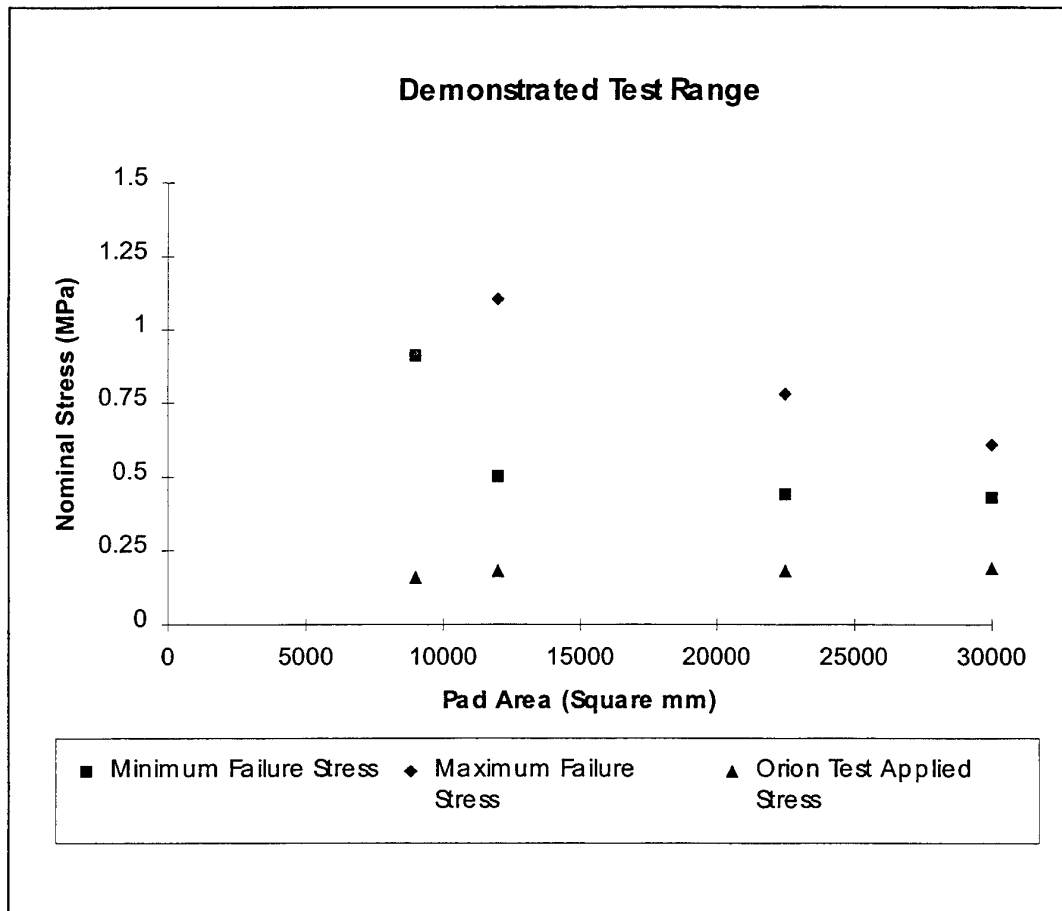


Figure 8: Results of tests on tension pad sizes to be used on the Orion wing leading edge test.

Appendix One - Bonding Process.

From tests performed on representative samples at AMRL the following bonding process has been proven to meet the design objectives of the tension loading pads.

1.1 Bonding system

The bonding system used to produce the tension pads described in this report has been supplied by Linatex Australia, 39 Corporate Avenue, Rowville, Victoria. The three parts to the adhesive system are sold as Solufix solution MP21 primer and Solufix 14A and Solufix 14B two part contact adhesive. The primer solution is toluene based and is a green-blue colour. The contact adhesive requires mixing of parts 14A and 14B to set, 14A is a thick pink liquid with a strong solvent smell containing both toluene and MEK while part 14B hardening solution is a brown liquid consisting mostly of methylene chloride.

The primer and adhesive are considered highly flammable and poisonous. Vapours are irritating to the respiratory tracts and the liquid is highly irritating to the skin and eyes. The bonding process should be carried out in a properly constructed and operational fume cupboard with adequate ventilation. Personnel handling the primer and bonding agents must wear safety eye wear, gloves, respirators and protective clothing. Any personnel using the bonding system should make themselves familiar with the material safety data sheets for the primer and adhesive.

1.2 Priming of metal surfaces.

To prime metal surfaces for bonding to rubber the following process is recommended.

1. Thoroughly clean and degrease metal surface to remove all traces of dirt and oils using a suitable cleaning agent such as Ardrex.
2. Sand blast metal surface to a "white" condition, ensuring all scale is removed. Particular attention should be paid to any edges.
3. Clean sand blasted surface with MEK using a tissue wipe. The surface should be wiped until no further trace of dirt or grit is evident on the tissue after wiping. Each wipe should be used once only and in a single pass so that surface contaminants are not returned onto the cleaned surface.
4. Prime cleaned surface with MP21 primer solution. This must be done as soon as possible after step 3 above to prevent surface oxidation. The primer is applied using a brush as an even coating over the surface without runs or areas of primer build up.
5. Let primed surfaces air dry in a controlled environment for a minimum of 12 hours.

1.3 Bonding rubber to primed metal surface.

To obtain a satisfactory bond strength for joining rubber to a primed metal surface the following process is recommended.

1. Buff the surface of the rubber to be attached to the metal.
2. Clean surface of buffed rubber with MEK using a tissue wipe. The surface should be wiped until no further trace of dirt or grit is evident on the tissue after wiping. Each wipe should be used once only and in a single pass so that surface contaminants are not returned onto the cleaned surface.
3. Thoroughly mix and stir Solufix 14A adhesive and Solufix 14B hardener in a ratio of 10:1 by weight (eg 100 gm 14A to 10 gm 14B) using only a sufficient quantity for the surface area to be joined.
4. When properly mixed apply an even coat of adhesive, using a brush, to both metal and rubber surfaces to be joined. Care should be taken when applying the first coat to the primed metal surface to use as few brush strokes as possible on the same area to prevent the primer coat lifting off. Ideally the adhesive should be applied in one single stroke.
5. Allow first coat of adhesive to dry for 20 minutes.
6. Apply second coat of adhesive to both surfaces. As with the first coat, the adhesive should be applied in even brush strokes using as few strokes as possible.
7. Allow the second coat of adhesive to dry for 20 minutes. The adhesive should be touch dry at the end of this period.
8. Align surfaces to be joined and bring together. As the adhesive will form a strong bond on contact extreme care must be used to ensure proper alignment. Use of a guide template or similar device is recommended. If proper alignment is not achieved then the bonded surface must be separated and the full bond process, including priming of the metal surface, is to be repeated.
9. Lightly clamp surfaces together and constrain to prevent any slippage during curing.
10. Place in a suitable oven and cure at the temperature and time specified. The adhesive will not over cure if left longer at temperatures of sixty degrees Celsius or less. Curing at ambient room temperature will require 3 to 4 days to obtain a maximum bond strength which is still less than can be obtained by heat curing. For further information on curing the adhesive contact Linatex.

For bonding the rubber to steel a cure temperature of 60 degrees Celsius for at least 4 hours has been found satisfactory while for bonding to aluminium a cure temperature of 45 degrees for a minimum of 6 hours gives a suitable bond strength.

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19. ABSTRACT Aerodynamic loads on aircraft lifting surfaces are often due to negative pressures acting on the outer skin of the structure. To simulate this type of loading, rubber pads bonded to the skin and loaded in tension can be used. This report describes the development of a contact adhesive based bonded rubber tension pad system for testing of an Orion P-3 wing leading edge.					